Terminal Bifurcation of the Biceps Brachii Muscle and Tendon: Anatomic Considerations and Clinical Implications

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OBJECTIVE. The objective of our study was to describe the anatomic variation of a bifurcated distal biceps tendon with MRI, histology, and dissection in cadavers and to report the MR appearance of superimposed lesions in a patient population with this anatomic variant.

MATERIALS AND METHODS. Visual and histologic examinations of the distal biceps brachii tendon in eight sectioned fresh-frozen elbow specimens were performed. Dissection of 17 elbow specimens was performed to describe the distal biceps brachii tendon. In addition, all elbow MRI reports over a 3-year period ($n = 411$) were retrospectively reviewed to determine the presence of bifurcation of the distal biceps brachii tendon.

RESULTS. The distal biceps brachii tendon appeared bifurcated in 25% of the sectioned specimens, and these findings were confirmed histologically. The distal biceps brachii tendon was completely separable into two components—that is, a short head and long head—throughout their proximal to distal extent in 41.2% of the dissected specimens. The distal biceps brachii tendon appeared bifurcated in 11.8% of 68 clinical cases that showed distal biceps brachii tendon abnormalities or injuries. The following patterns of injury were noted: complete rupture of both tendons ($n = 1$), complete rupture of the short head and normal insertion of the long head ($n = 2$), complete rupture of the short head and partial tear of the long head ($n = 2$), partial tear of both tendons ($n = 2$), and complete rupture of the short head and tendinosis in the long head ($n = 1$).

CONCLUSION. A bifurcated distal biceps brachii tendon is an anatomic variant that arises from persistent division between the short head and long head of the distal biceps brachii tendon and can be characterized with MRI. Knowledge of a bifurcated distal biceps brachii tendon is important to characterize injury to the components and to avoid pitfalls in imaging diagnosis.

Keywords: anatomic variants, biceps brachii muscle, biceps brachii tendon, elbow injury, sports medicine

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Although abnormalities and injuries of the distal biceps brachii tendon are less common than those of its proximal counterpart, the distal biceps brachii tendon is subject to the same spectrum of abnormalities that requires not only correct diagnosis but also accurate characterization to appropriately guide therapy. There is no uniformly accepted system for the classification of distal biceps brachii tendon injuries, and the complex soft-tissue and osseous anatomy of this structure has not been addressed in a detailed fashion in the literature. Injuries of the distal biceps brachii tendon can include tendinosis and partial- and full-thickness tears [1]. Distinguishing between high-grade partial- and full-thickness tears of the distal biceps brachii tendon on the basis of imaging findings or clinical examination results can be challenging. Distal biceps brachii tendon rupture is relatively rare and has been reported with an incidence of 1.2 occurrences per 100,000 persons per year [2].

Successful surgical repair of a ruptured distal biceps brachii tendon is predicated on an understanding of the anatomy of the distal biceps tendon and its relationship to the radial tuberosity. Some anatomic aspects of the distal biceps brachii tendon are described in classic anatomy texts. However, the detailed anatomy of the distal biceps muscle and tendon and its relationship to the radial tuberosity have received little attention.

The purpose of our study was to describe the detailed topography of the distal biceps brachii tendon by stratigraphic dissection of embalmed specimens and by MRI with histologic correlation of fresh elbow specimens. In addition, we assessed the MR appearances

of distal biceps brachii tendon injuries in a patient population with a bifurcated terminal biceps brachii tendon. To our knowledge, such detailed topographic analyses of the normal and injured distal biceps brachii tendon have not been reported.

Materials and Methods

Stratigraphic Dissection of Embalmed Specimens

Stratigraphic dissection of 17 anatomic elbow specimens (seven left elbows, 10 right elbows; nine male cadavers and eight female cadavers; mean age at death, 75 years) fixed with a mixture of formol and carbolic acid was performed. To avoid sampling and observer bias, the elbows were randomly selected from available cadavers by anatomy assistants not involved in the research group. Only separated single elbows were then transferred and dissected by the authors.

During each step of stratigraphic dissection, each specimen was photographed. To distinguish the several parts of the biceps brachii muscle in the embalmed specimens, we used differently colored vessel loops. Thus, the long head—or caput longum musculi bicipitis brachii—was marked with a red vessel loop, its short head—or caput breve musculi bicipitis brachii—with a blue loop, and the distal biceps brachii tendon with a white vessel loop. If long and short head contributions could be identified in the biceps brachii tendon, they were highlighted by a white–red and white–blue vessel loop, respectively.

MRI, Visual Inspection, and Histologic Analysis of Fresh-Frozen Elbow Specimens

Eight fresh-frozen anatomic specimens of human elbows from seven persons (two left elbows, six right elbows; age range at the time of death, 60–83 years; mean age, 74 years) were obtained. Frontal and lateral radiographs of each anatomic specimen were obtained to ensure that the elbows were not affected by surgical alterations or significant pathologic abnormalities as determined in consensus by two authors with 30 and 10 years of experience, respectively, in interpreting musculoskeletal radiographs. The cadaveric specimens were immediately frozen at –40°C (Bio-Freezer, Forma Scientific). The specimens were later allowed to thaw for 24 hours at room temperature before MRI. The elbow specimens were obtained and used according to institutional guidelines, and informed consent for research was obtained from relatives of the deceased.

MR images were acquired with a 1.5-T superconducting magnet (Signa, GE Healthcare) and a small standard flexible surface coil (Flex Coil, Medical Advances). All cadaveric elbows were imaged in the coronal, transverse, and sagittal planes. The MRI protocol consisted of T1-weighted spin-echo sequences (TR/TE, 466.7/10.0) in sagittal, coronal, and transverse planes. To acquire high-spatial-resolution images, a section thickness of 2.5 mm, intersection gap of 0.5 mm, field of view of 13 cm, and data acquisition matrix of 256 × 224 were used.

After completion of MR scanning, the fresh elbow specimens were frozen again at –40°C (Forma Bio-Freezer, Forma Scientific) for more than 120 hours. The frozen specimens were then sectioned using a band saw into 3-mm slices in the axial ($n = 3$), coronal ($n = 2$), and sagittal ($n = 3$) planes corresponding closely to the sections at MRI. After the debris had been rinsed from the surface of the specimens, the sections were thawed and then photographed under floodlighting with a digital camera (Nikon Coolpix 990). To describe the anatomic appearance of the distal biceps brachii tendon from the musculotendinous junction to the radial insertion, the findings on MR images of each specimen were compared with the findings derived from visual inspection of the cadaveric slices by three authors.

To analyze the composition of the fibers of the distal biceps brachii tendon, histologic samples of this structure were collected from four elbow specimens. Samples were chosen on the basis of findings at visual inspection of the sectioned fresh-frozen elbow specimens. Two of these specimens appeared to have a bifurcated distal biceps brachii tendon and two other specimens appeared to have a one-bundle distal biceps brachii tendon. In each of the four specimens, the tendon was analyzed at two levels: first, at the insertion of the tendon in the radius; and, second, at a point midway between the musculotendinous junction and the distal tendinous attachment site.

For histologic analysis, specimens were suspended in a 10% formalin solution. Samples were embedded in paraffin and sectioned further into 5-µm-thick slices. Histologic slices were stained with H and E stain and analyzed at light microscopy (magnification, ×2–×4), by an orthopedic pathologist with 30 years of experience. A pathologist and radiologist together recorded whether the distal biceps brachii tendon appeared bifurcated and recorded its histologic nature at both of the sites chosen for analysis.

Clinical Cases

All elbow MRI reports from two patient populations over a 3-year period (2004–2006) were retrospectively reviewed. Institutional review board approval was obtained for review of these clinical cases. A total of 411 elbow MR studies were performed during the study period, of which 68 were reported to show a distal biceps brachii tendon injury or injuries. All studies with a diagnosis of distal biceps brachii tendon injury were reviewed by three radiologists trained in musculoskeletal imaging in consensus.

MR images were acquired using one of two 1.5-T superconducting magnets (Excite, GE Healthcare; or Magnetom Vision, Siemens Medical Solutions). The MRI protocol of the clinical cases consisted of T1-weighted spin-echo, proton density–weighted, and short T1 inversion recovery–weighted sequences in the axial plane; a short T1 inversion recovery–weighted sequence in the sagittal plane; and a fat-suppressed proton density–weighted sequence in the coronal plane.

In the 68 elbow MR studies with a diagnosis of distal biceps brachii tendon injury, the biceps brachii tendon was surveyed from its musculotendinous junction to its distal radial attachment site; the contributions of the short head and long head were noted to determine whether tendon bifurcation was present and, if so, its degree. In cases in which the distal biceps brachii tendon appeared bifurcated the distal tendinous contributions of the short head and long head of the distal biceps brachii muscle were surveyed for evidence of tendinosis, partial tears, and complete tears using standard MRI criteria. The criterion for complete tendon rupture was absence of the short head, long head, or both heads of the distal biceps brachii tendon fibers at the site of insertion on the radial tuberosity. Partial tears were diagnosed on the basis of an abnormal tendon diameter and the presence of increased intratendinous signal intensity paralleling that of fluid. Tendon diameter was judged subjectively and was classified as either increased or decreased compared with the diameters of the more proximal segments of the distal biceps brachii tendon. Tendinosis was diagnosed on the basis of the presence of increased intratendinous signal intensity that did not parallel joint fluid or of an abnormal tendon diameter.

Abnormalities to the short and long heads of the biceps tendon were localized through the application of three criteria based on the existing literature and our experience with dissected specimens: first, following the course of the tendon abnormality proximally to the level of the musculotendinous junction; second, ulnar (short head) versus radial (long head) location of the tendon; and, third, distal and anterior (short head) versus proximal and posterior (long head) attachment site to the radial tuberosity [3, 4]. The fluid in the interosseous bursa of the elbow and in the bicipitoradialis bursa was investigated and documented in all elbow MR examinations of the patients.

Results

Stratigraphic Dissection of Embalmed Specimens

Musculotendinous junction and "goose quill"—In the anatomic dissections of 17 elbow specimens, we attempted to separate the two muscle bellies and explore the distal extent of their tendons to the ultimate site of insertion, noting the presence and degree of individual short and long head components throughout the course. We found that at the myotendinous junction separation of both bellies was hindered by a partial decussation of the muscle and tendinous fibers. We termed this area "goose quill" because of its resemblance to a goose's feather (Fig. 1). The goose quill had a median length of 2.0 cm (interquartile range 1, 1.0–1.6 cm; interquartile range 3, 2.7–3.0 cm).

Bicipital aponeurosis—In most cases (94.1%), the bicipital aponeurosis (i.e., lacertus fibrosus) was formed by superficial tendinous fibers arising from both muscle bellies (Fig. 2). In one case, the short head formed a flat and strong bicipital aponeurosis reaching the medial side and inserting via the antebrachial fascia on the dorsal border of the ulna. In 5.9% (1/17) of the specimens, fibers of only the short head of the biceps brachii tendon contributed to the bicipital aponeurosis. In 76.5% of the specimens, the bicipital aponeurosis showed a single insertion on the medial side of the forearm. Its fibers intermingled with the reinforced part of the antebrachial fascia covering the superficial flexors of the forearm.

Distal biceps tendon—In 11.8% (2/17) of the specimens, only the long head of the biceps tendon attached at the radial tuberosity. In 88.2% (15/17) of the specimens, a common biceps brachii tendon composed of both the short and long head components inserted at the radial tuberosity. In these cases, the common biceps brachii tendon had two macroscopically identifiable components representing the short head and long head. In 41.2% of these cases, the short head and long head were completely separable into two components along their course (Fig. 3).

MRI, Visual Inspection, and Histologic Analysis of Fresh-Frozen Elbow Specimens

Separation of the two muscle bellies (i.e., short head and long head) with their distal continuation as individual tendons was seen in two of eight (25%) specimens on MR images and visual inspection of the anatomic sections. MR images of these two specimens revealed separable short head and long head components from the musculotendinous junction to a point 3.3 cm distally in one elbow specimen and 3.6 cm distally in the other elbow specimen. The separation was best visualized on axial and coronal MR images. The short head and long head of the distal biceps brachii tendon were separated by a linear region of fat.

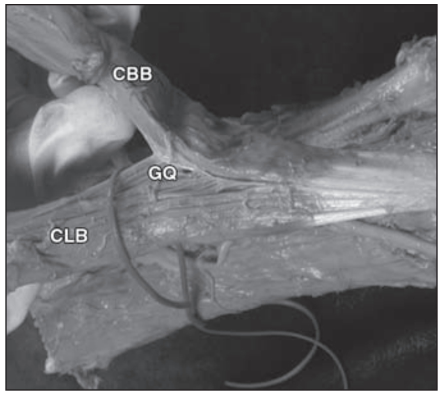

Fig. 1—Photograph of dissected cadaveric elbow shows area of decussation of fibers of both muscle bellies that we termed "goose quill" (GQ). CBB = caput breve musculi bicipitis brachii, CLB = caput longum musculi bicipitis brachii.

At the insertion to the radial tuberosity, the distal biceps brachii tendon had the MRI appearance of a single bundle in both specimens. On visual inspection, similar findings were apparent. These findings were confirmed on histologic analysis in the region of the bifurcated distal biceps brachii tendon in which the short and long heads were separated by a plane of fatty tissue (Fig. 4). In six of eight (75%) specimens, the distal biceps brachii tendon was seen as one bundle from its proximal to distal extent at both MRI and visual inspection.

Four histologic samples collected from two of the elbow specimens that appeared to have a one-bundle distal biceps brachii tendon on MRI and visual inspection served as a control group. The one-bundle appearance was confirmed in one of the specimens. In the second specimen, however, fat and a thin, fibrous tissue septum separated the central tendon into short head and long head components on microscopic examination. Around the central separation zone, the tendon fibers were smaller than their peripheral counterparts in both the short head and long head (Fig. 5).

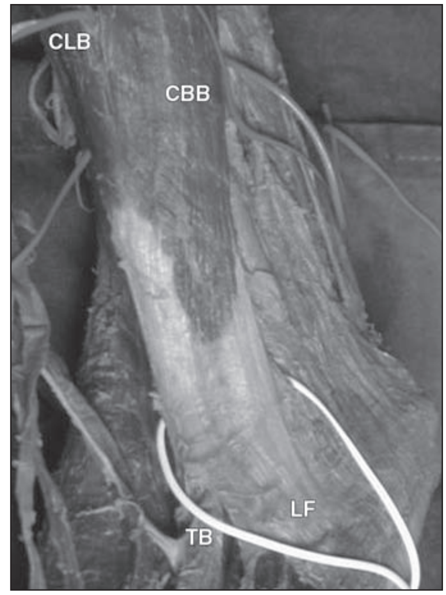

Fig. 2—Embalmed specimen of adult human left cubital fossa. Biceps brachii muscle with its tendon and bicipital aponeurosis have been dissected. Note that bicipital aponeurosis (lacertus fibrosus [LF]) is formed by fibers of long (caput longum musculi bicipitis brachii [CLB]) and short (caput breve musculi bicipitis brachii [CBB]) heads of biceps brachii muscle. TB indicates tendon of biceps brachii muscle inserting into radial tuberosity.

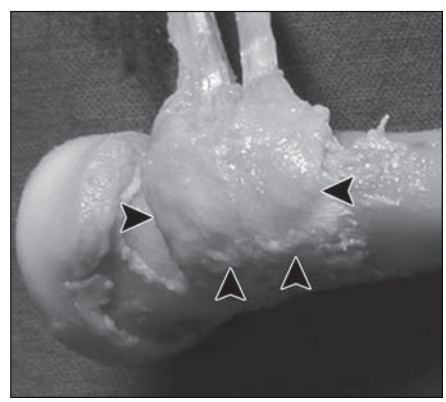

Fig. 3—Photograph of dissected cadaveric radial tuberosity (*arrowheads*) with insertion of tendon of biceps muscle. Note that tendon inserts over whole plane of tuberosity and that in this case tendon fibers can be assigned to individual muscle bellies—that is, more proximally situated tendon springs off from long head and more distally inserting tendon, from short head.

Clinical Cases

On MRI studies, the distal biceps brachii tendon appeared bifurcated in eight of the 68 (11.8%) elbows that had a distal biceps brachii tendon injury. In all eight cases, the patients were men (six left elbows, two right elbows); they ranged in age from 35 to 66 years, with a mean age of 48.5 ± 10.6 (SD) years.

The following patterns of injury were noted in patients with a bifurcated-appearing distal biceps brachii tendon. In one of eight

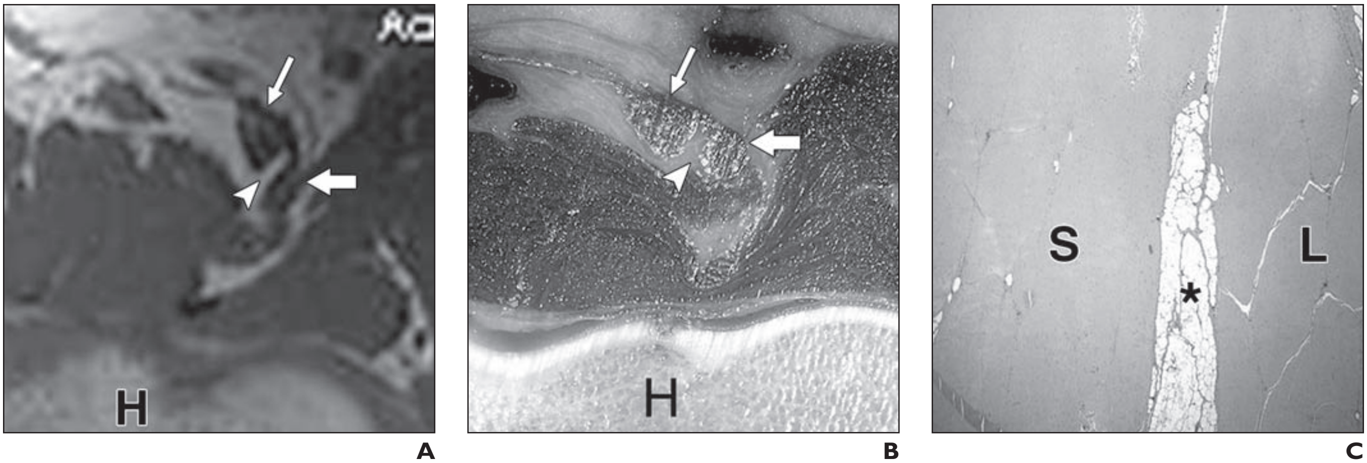

Fig. 4—Bifurcated distal biceps tendon in left elbow specimen of male cadaver (age at death, 83 years).
A and **B,** Axial spin-echo T1-weighted MR image (**A**) and axial 3-mm-thick anatomic slice (**B**) show separated short head (*thin arrow*) and long head (*thick arrow*) of distal biceps tendon with fat (*arrowhead*). H = humerus.
C, Photomicrograph of histologic section shows fat cells (*asterisk*) between short head (S) and long head (L) of bifurcated biceps tendon. (H and E, ×2)

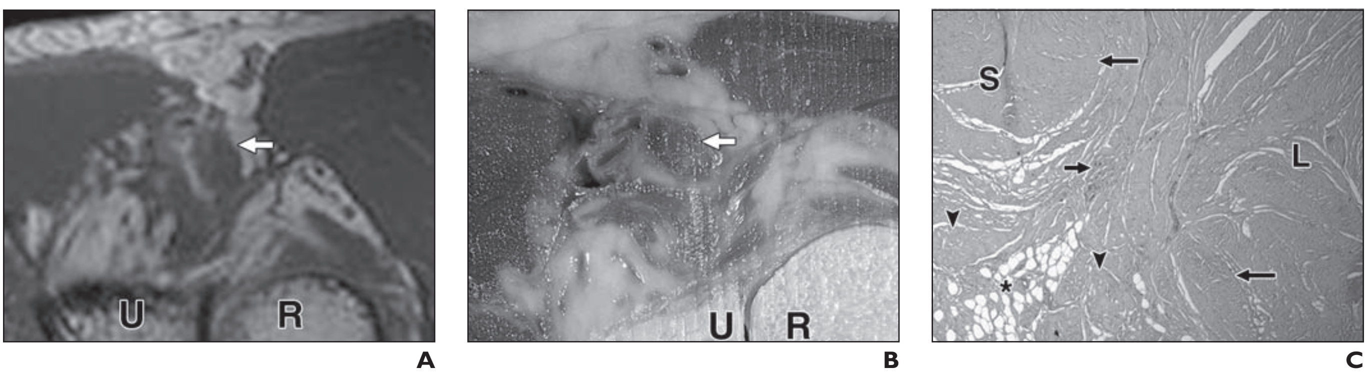

Fig. 5—One-bundle appearance of distal biceps tendon in left elbow specimen of 74-year-old man at MRI and on visual inspection. Biceps tendon was separated into short head and long head components on microscopic examination.
A and **B,** Axial spin-echo T1-weighted MR image (**A**) and axial 3-mm-thick anatomic slice (**B**) show nonseparated, one-bundle short head (*arrow*). U = ulna, R = radius.
C, Photomicrograph of histologic section shows thin, fibrous tissue septum (*short arrow*) and fat tissue (*asterisk*) that separate distal biceps tendon into short head (S) and long head (L) components. Around central separation zone, tendon fibers (*arrowheads*) are smaller than peripheral counterparts (*long arrows*) in both short and long heads. (H and E, ×4)

(12.5%) cases, complete rupture of both the short and long heads of the distal biceps brachii tendon was detected. In two of eight (25%) cases, complete rupture of the short head of the distal biceps brachii tendon and normal insertion of the long head were seen (Fig. 6). In two of eight (25%) cases, complete rupture of the short head of the distal biceps brachii tendon and a partial tear of the long head were present. In two of eight (25%) cases, partial tears of both heads of the distal biceps brachii tendon were identified (Fig. 7). In one of eight (12.5%) cases, complete rupture of the short head of the distal biceps brachii tendon and tendinosis in the long head were noted (Fig. 8).

In a single case, a partial tear of the long head of the distal biceps brachii tendon was located at the level of the musculotendinous junction. In all other cases of distal biceps brachii tendon injury with tendon abnormalities of the short or long head, lesions were observed near the radial tuberosity. In one of eight (12.5%) cases, some fibers of the short head finished at the level of the bicipital aponeurosis (Fig. 7C). Fluid in the interosseous bursa was seen in all cases. Seven of eight (87.5%) cases had fluid in the bicipitoradial bursa.

Four of the eight patients underwent surgery. We had access to operative results for only two of the four. In one of these patients, the MRI findings of a bifid distal biceps brachii tendon, total rupture of the short head, and partial tear of the long head were confirmed. The rupture of the short head was repaired into the radius with the EndoButton fixation technique (continuous loop of polyester tape, Smith & Nephew). In the other patient who underwent surgery of the bifid distal biceps brachii tendon, total rupture of the short head and partial tear of the long head were confirmed, just as the MR images indicated. The total rupture of the short head was repaired with an interpositional graft from the flexor carpi radialis muscle. One patient who had total rupture of the short head and a normal long head of the distal biceps brachii tendon and one patient who had total rupture of the short and long heads underwent surgery at outside hospitals and we could not obtain access to the surgical reports. The other four cases were treated conservatively.

Discussion

The biceps brachii muscle originates with its long head from the supraglenoid tubercle and with its short head from the coracoid process

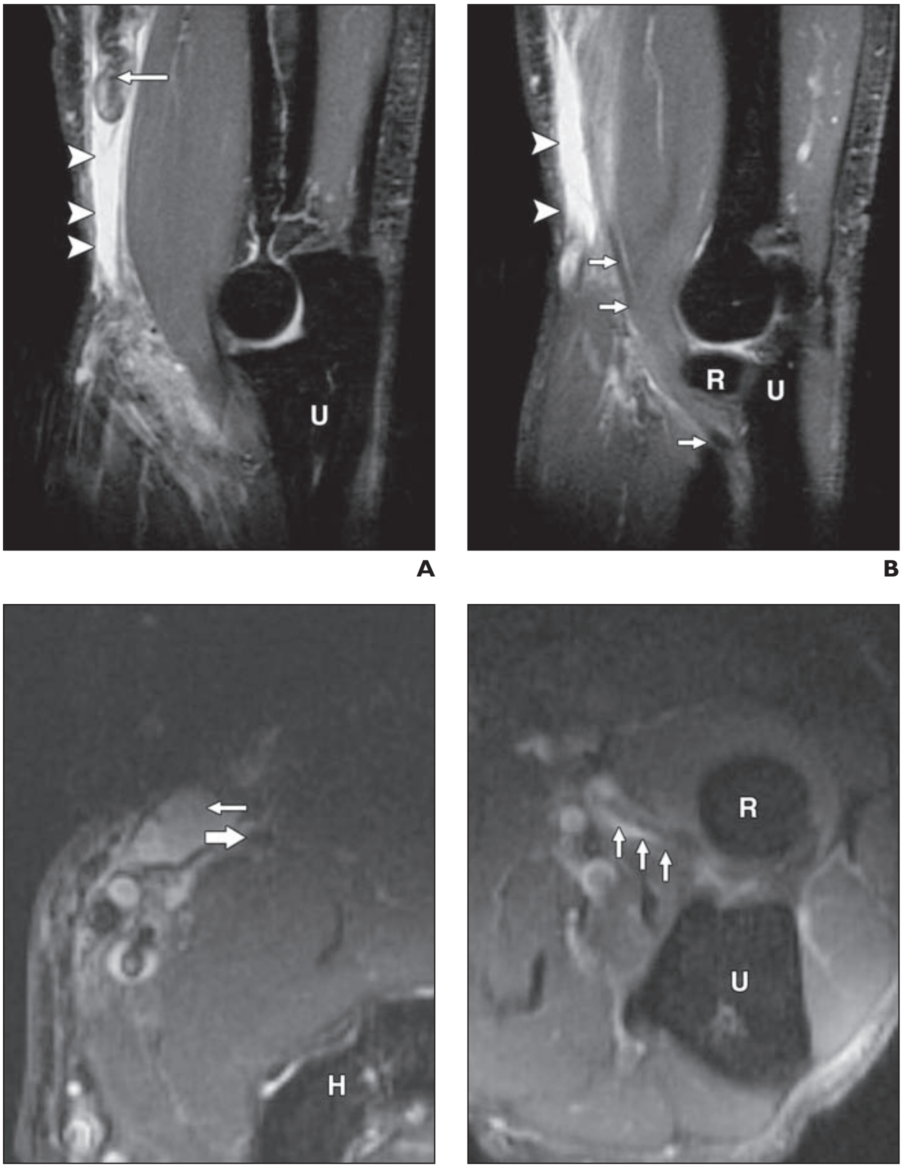

Fig. 6—Complete rupture of short head and normal long head of bifurcated distal biceps brachii tendon in left elbow of 61-year-old man. H = humerus, U = ulna, R = radius.
A, Sagittal short T1 inversion recovery–weighted image shows complete rupture and proximal retraction of short head of biceps brachii tendon (*arrow*) and fluid signal filled into gap (*arrowheads*).
B, Sagittal short T1 inversion recovery–weighted image shows normal long head (*arrows*) and fluid filled into gap (*arrowheads*) of ruptured short head of biceps brachii tendon.
C, Axial short T1 inversion recovery–weighted image shows fluid filled into gap of ruptured short head (*thin arrow*) and normal long head (*thick arrow*) of biceps brachii tendon.
D, Axial short T1 inversion recovery–weighted image shows fluid signal (*arrows*) surrounds normal radial attachment site of long head of biceps brachii tendon.

of the scapula. Both heads gradually become attached to each other while they descend on the anterior aspect of the upper arm. Proximal to the level of the elbow joint, again two tendons are formed by the incompletely united muscle bellies. The partial coalescence of both heads is created by a crossover of several muscle fiber bundles that we call “goose quill.” The main tendon of insertion formed by deep tendinous fibers originating from both heads enters the cubital fossa on its lateral aspect and is attached to the radial tuberosity. Furthermore, superficial tendinous fibers of both muscle bellies form an aponeurotic sheet that reinforces the antebrachial fascia and is attached via this fascia to the dorsal border of the ulna (Fig. 9).

As the biceps brachii muscle extends from the scapula to the forearm, it acts in the shoulder joint as well as in the elbow and radioulnar joints. Acting on the shoulder joint, the biceps brachii muscle creates anteversion of the arm, whereas acting on the elbow and radioulnar joints, it is a powerful supinator of the forearm via its insertion on the radial tuberosity. This movement is especially useful for screw driving. When the forearm is in the supine position, the biceps brachii muscle—together with the brachialis muscle and all the forearm muscles arising from the medial epicondyle of the humerus—flexes the elbow.

Although abnormalities and injuries of the distal aspect of the biceps brachii tendon have been reported to be relatively rare as compared with those of the proximal aspect, successful treatment requires an understanding of normal anatomy, anatomic variants, and patterns of abnormalities and injuries. Contemporary anatomic descriptions of the biceps brachii muscle and the elbow joint offer only a generalized description of the distal biceps brachii tendon, bicipital aponeurosis, and insertion of the tendon at the radial tuberosity [5, 6].

The anterior part of the distal biceps brachii tendon receives the fibers of the short head and the posterior part, those of the long head. A twisting of the tendinous fibers arising from the short head and long head and their respective contribution to the anterior and posterior part of the distal biceps brachii tendon, resulting in either distal or proximal insertion at the radial tuberosity, have been described in anatomy texts and recently in the orthopedics literature [3, 4, 6, 7]. The stratigraphic dissections performed for our study allowed us to divide the biceps tendon into three parts arranged from its proximal to distal extent: the goose quill and musculotendinous junction, the bicipital aponeurosis, and the distal portion of the biceps brachii tendon.

The goose quill structure has been described in neither the modern [5, 6] nor the traditional [8] anatomy literature, to our knowledge. At the myotendinous junction, separation of both muscle bellies was hindered by a partial decussation of the muscle and tendinous fibers. We termed this area “goose quill” because of its resemblance to a goose’s feather. The goose quill contradicts the postulate that the tendon can be split easily from the level of the muscle to the radial tuberosity. We believe that the quill’s function is to optimize the transformation of muscle contraction into optimal flexion and supination at

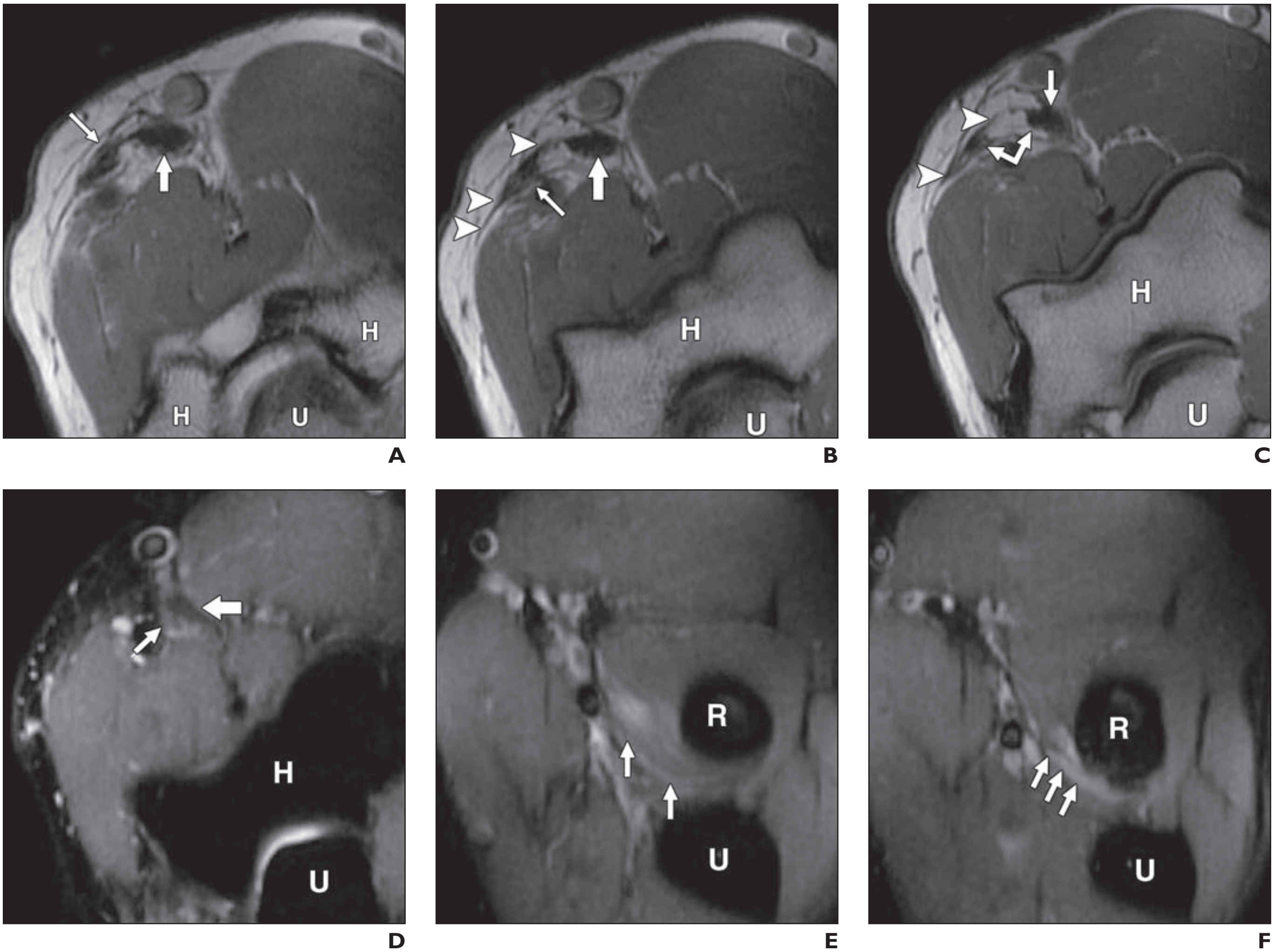

Fig. 7—Partial tear of both short head and long head of bifurcated distal biceps brachii tendon in left elbow of 41-year-old man. H = humerus, U = ulna, R = radius.
A, Axial proton density–weighted MR image shows proximal portions of both short (*thin arrow*) and long (*thick arrow*) heads of bifurcated distal biceps brachii tendon.
B, Axial proton density–weighted MR image shows some fibers of short head (*thin arrow*) that finish at level of lacertus fibrosus (*arrowheads*) and normal appearance of long head (*thick arrow*) of biceps brachii tendon.
C, Axial proton density–weighted MR image shows normal signal in short head (*double arrows*) and long head (*single arrow*) of biceps brachii tendon. Arrowheads indicate bicipital aponeurosis.
D, Axial short T1 inversion recovery–weighted image shows high signal in attenuated short head (*thin arrow*) and intermediate signal in normal-sized long head (*thick arrow*) of biceps brachii tendon.
E, Axial short T1 inversion recovery–weighted image shows high signal in attenuated radial attachment site of long head of biceps brachii tendon (*arrows*), which indicates partial tear.
F, Axial short T1 inversion recovery–weighted image shows high signal in attenuated radial attachment site of short head of biceps brachii tendon (*arrows*), which indicates partial tear.

the same time by aligning the power vector of the two muscle heads. Although the goose quill does not facilitate identification of the short and long head components of the biceps tendon to the bicipital aponeurosis, it does not obscure visualization of the bifurcated distal biceps brachii tendon.

In 94.1% of the embalmed elbow specimens, the bicipital aponeurosis was formed by superficial fibers originating from both muscle heads. Clear distinction of their origins by mere blunt dissection was not possible. The fibers could be separated artificially only by dissecting the tendon parallel to the direction of its fibers with a scalpel. In 5.9% of the embalmed elbow specimens, the bicipital aponeurosis was formed by superficial fibers originating from only the short head. In one of the clinical cases (12.5%), the short head alone comprised the bicipital aponeurosis. These findings illustrate the importance of closely surveying the short head and long head of the distal biceps brachii tendon throughout their distal extent because they offer varying contributions not only to the distal tendon attachment but also to the bicipital aponeurosis.

Investigators have suggested that in cases of biceps tendon injury anatomic repair to both the distal tendon and the bicipital aponeurosis are required to prevent the known complication of decreased range of elbow motion—specifically, of supination [3]. It is likely that during the performance of elbow surgery the function of the bicipital aponeurosis—that is, drawing the posterior

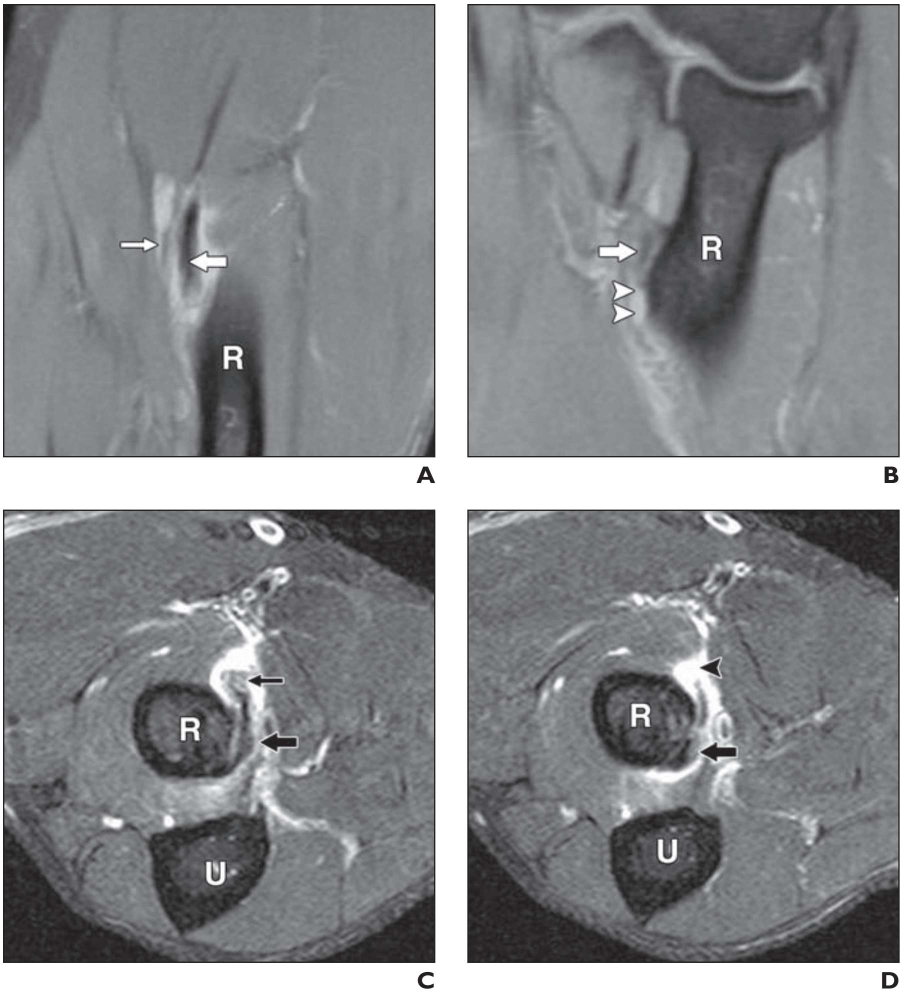

Fig. 8—Complete rupture of short head and tendinosis of long head of bifurcated distal biceps brachii tendon in right elbow of 42-year-old man. R = radius, U = ulna.
A, Coronal fat-suppressed proton density–weighted MR image shows high signal in moderately retracted, ruptured short head (*thin arrow*) and normal appearance of long head (*thick arrow*) of biceps brachii tendon.
B, Coronal fat-suppressed proton density–weighted MR image shows high signal in blank space of radial attachment area of complete ruptured short head (*arrowheads*) and high signal in radial attachment site of long head (*arrow*) of biceps brachii tendon.
C, Axial short T1 inversion recovery–weighted image shows high signal in moderately retracted, ruptured short head (*thin arrow*) and moderate thickening and signal increase in long head (*thick arrow*) of distal biceps brachii tendon.
D, Axial short T1 inversion recovery–weighted image shows fluid in blank space of radial attachment area of complete ruptured short head (*arrowhead*) and radial attachment site of long head (*arrow*) of biceps brachii tendon.

border of the ulna medially to elicit supination of the forearm—should be emphasized. Thus, by repairing a disrupted bicipital aponeurosis accompanying a rupture of the distal biceps brachii tendon, the traction on the ulna can be restored. Although this concept has been introduced in current surgical research [3, 9], suture fixation of the torn bicipital aponeurosis is not proposed.

As we previously noted, in most dissected distal biceps brachii tendons in our study, the distal tendon was composed of macroscopically distinct short and long head components, with half being completely separate tendons. Additional variations in the distal biceps tendon included a distal tendon that was composed solely of the long head, with the short head forming the bicipital aponeurosis alone in one case. In the other case, the short head formed the bicipital aponeurosis and provided an attachment to the coronoid process. Such variations related to the formation of the biceps tendon [6, 8] have not been described to our knowledge.

The results are largely supported by the MRI–anatomic correlation component of our study as well as the results of a recent study in the orthopedics literature in which 10 of 17 embalmed dissected specimens had two separate short and long head muscle bellies and distal tendons throughout their entire course [4]. In some cases, the anatomic variation of a bifurcated distal biceps brachii tendon can be identified on MRI as well as by gross inspection and histologic evaluation. In other cases, a bifurcation is present but is not identifiable on MRI.

In applying the results of the dissection and MRI–anatomic correlation components of our study to the retrospective review of clinical images, a systematic approach to determine short versus long head involvement in the setting of abnormalities or injuries to a distally bifurcated biceps tendon can be established. Moreover, in applying this system, we were able to characterize several patterns of distal tendon injury in the bifurcated tendon.

We are aware of only a single case report that has described rupture of a medial tendon in a patient with a bifurcated distal biceps brachii tendon. In that case, a completely unfused and bifurcated distal biceps brachii muscle–tendon unit was described at surgery and repaired [10]. Before surgery, however, a mistaken diagnosis of a complete rupture of the distal biceps brachii tendon was made.

One of the limitations of our study is the small number of cadaveric specimens. Although only eight fresh-frozen elbow specimens were sectioned, we believe the findings are significant because we correlated our findings with histologic analysis in specimens. In addition, dissection of 17 embalmed elbow specimens was performed to describe the distal biceps brachii tendon.

We recognize that looking at consecutive MR studies to determine the prevalence of a finding on MRI is better than looking only at cases with abnormal findings. Although that strategy is ideal, the histologic component of our study dictates that the true incidence will be underestimated. We chose to look only at cases with abnormal findings.

Use of the flexed abducted supinated view while MRI was performed of the frozen elbow specimens or the clinical cases might have helped better visualize the distal biceps brachii tendon [11]; however, the frozen elbow specimens were sectioned in the axial, coronal, and sagittal planes, corresponding closely to the sections at MRI. The findings on MR images of each specimen were compared with

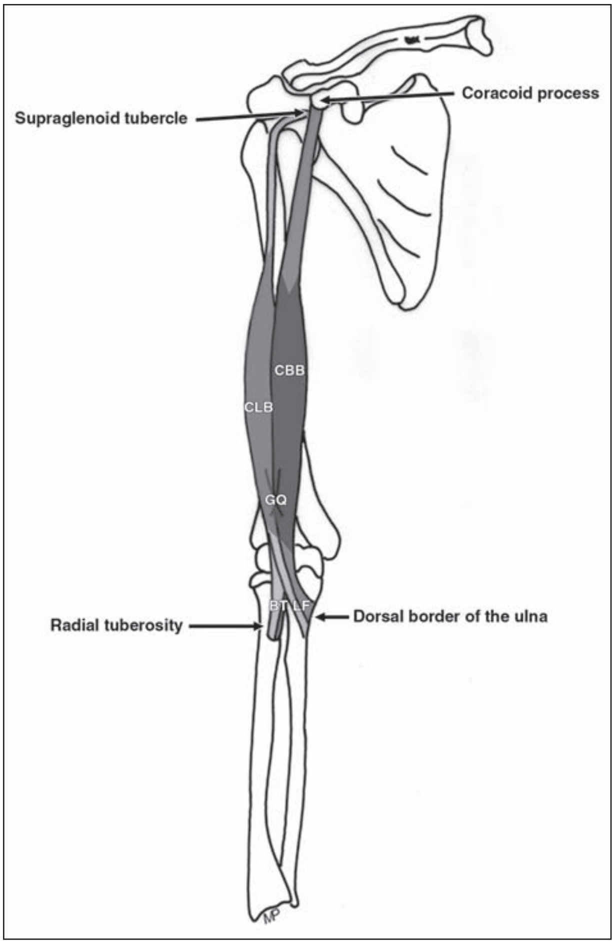

Fig. 9—Schematic drawing illustrates anatomy of biceps brachii muscle. Note different origins of both heads as well as formation of fiber decussation in distal aspect of muscle, "goose quill" (GQ). To different extents, long (caput longum musculi bicipitis brachii [CLB]) and short head (caput breve musculi bicipitis brachii [CBB]) contribute tendinous fibers for tendons of insertions. With main tendon (BT), muscle is attached to radial tuberosity and with superficial aponeurotic layer, lacertus fibrosus (LF), it reaches dorsal border of ulna.

the findings derived from visual inspection of the cadaveric slices. The comparison between the findings on flexed abducted supinated MR images of the elbow specimens with the findings derived from visual inspection of the cadaveric slices in these three routine sectioning planes was not possible. For the clinical cases, all elbow MR studies with a diagnosis of distal biceps brachii tendon injury over a 3-year period were retrospectively reviewed. Unfortunately, these MR images did not include the flexed abducted supinated view. Therefore, we could not use the flexed abducted supinated MRI view in our study. Although the MR studies were performed to describe possible injury and the bifurcated appearance of the distal biceps brachii tendon, adding the flexed abducted supinated view to the MR examination may be helpful.

The other limitation of our study is the lack of operative correlation of all clinical cases. Many of the patients were treated conservatively and two patients were lost to follow-up.

In conclusion, although injury of the distal biceps brachii tendon is a relatively uncommon event, its accurate diagnosis and precise characterization are crucial for the appropriate clinical management and optimal outcome. The results of the various components of our study have shown that anatomic variations exist at the level of the musculotendinous junction of the biceps tendon, the bicipital aponeurosis, and the distal tendon. We emphasize that terminal bifurcation in the distal biceps brachii tendon is not rare and that the presence of this anatomic variation can introduce pitfalls in imaging diagnosis in the setting of an injury. We also have illustrated a variety of superimposed abnormalities and injuries in the setting of the bifurcated distal biceps tendon including partial tears, complete ruptures, and tendinosis with variable involvement of the short and long heads in eight clinical cases on MRI. These observations, combined with those detailed in several recently published articles, may lead to new techniques to anatomically repair the injured distal portion of the distal biceps brachii tendon.

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